

Surface Plasmon Tunable Color Filter and Projection Display

Yu Wang

Jet Propulsion Laboratory
California Institute of Technology, Pasadena, CA 91009

A novel projection display, based on a new phenomenon of voltage-induced color-selective absorption with surface plasmons, are able to generate bright image on a large screen with high efficiency. In addition, neither color filters nor phosphors are needed to generate the color. With the incident beam of $\pm 7^\circ$ half cone angle, the color purity of this device can be as good as the CRT displays, and the contrast ratio can reach over 200:1. System analysis shows that, for a color sequential single panel 1.8" surface plasmon projector, the luminous efficiency can reach 3 lumens/Watt.

1. Introduction

The market of projection display has been growing rapidly in recent years. Though the CRT projectors still leading the way, many flat panel projector models have been introduced. While the brightness and efficiency are still big concerns, many flat panel projectors suffer with low manufacture yields and complex structures, which keep the prices high.

Here I introduce the surface plasmon (SP) projection displays, which are based on a new phenomenon of voltage-induced color-selective absorption with surface plasmons¹, is able to achieve high brightness and high efficiency. In addition, this device can generate the colors without color filters. The optical system is much simpler than the current projectors, which can reduce the size and manufacturing cost.

It is well known that, for prism coupling, SP waves can be generated at a metal/dielectric interface. At this SP resonance, the reflected light vanishes -- attenuated total reflection (ATR)². This resonance depends on the dielectric constants of both the metal and the dielectric. When a voltage is used to change the dielectric constant of the dielectric, the reflected light can be modulated³⁻⁵. Because of their big birefringence, liquid crystals are among the best materials for surface plasmon light modulator. A contrast ratio over 100 and spectral resolution better than 10

lines/mm had been reported for SP light modulator using laser beam^{6,7}.

If a white light is used instead of the laser beam, then only these photons in S1' resonance range will be absorbed, and for those photons out of the resonance will be totally reflected, which means the reflected light becomes colored. This is so called S1' voltage-induced color-selective absorption. If a voltage is used to change the index of the liquid crystal, then the S1' resonance will change, and the reflected light will show the change of the complementary color. Depending on the metal film used, the S1' resonance could cover just 1/3 of the visible spectrum, which can be used for a tunable field sequential color filter, or cover all of the visible spectrum, which can be used as a light modulators.

3. S1' tunable color filter

The structure of S1' tunable color filter is shown in Fig. 1. This tunable color filter can replace the color wheel used in other projection devices. The incident p-polarized white light is reflected three times by Unit-1, Unit-2 and Unit-3 to provide the sequential primary colors. Initially, when the applied voltages are zero, Unit-1 is set at SP resonance of red, Unit-2 is set at S1' resonance of green, and Unit-3 is set at the S1' resonance of blue. All of the visible lights are absorbed, and there is no outgoing light. If a voltage is added on Unit-1, then the red color is off S1' resonance, the final outgoing light is red. If a voltage is added on Unit-2 instead, then the green color is off S1' resonance, the final outgoing light is green. Same if a voltage is added on Unit-3 instead, then the blue color is off S1' resonance, the final outgoing light is blue. By turning the voltage on these three units on and off sequentially, we can generate the sequential primary colors.

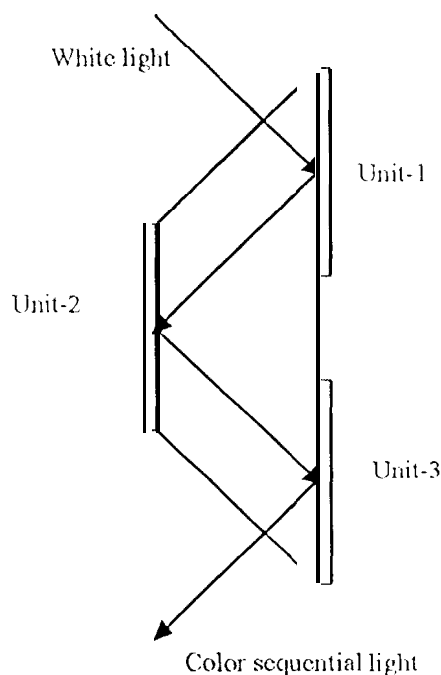


Fig. 1. Surface plasmon tunable color filter. The sequential primary colors are generated by color subtraction.

A theoretical calculation of three absorption curves at each interface are shown in Fig. 2. Here the metal films are multiple layer films to provide optimum spectrum range. At a given time, only one absorption curve is being pushed off SP resonance, and the outgoing light show the corresponding color. Theoretical calculation indicates that for an incident beam divergence of $\pm 7^\circ$

half cone angle the excellent colors can be generated. The color purities of the primary colors are shown in Fig. 3. as the heavy solid line, we can see the color purity is better than 27" CRT display (the light line.).

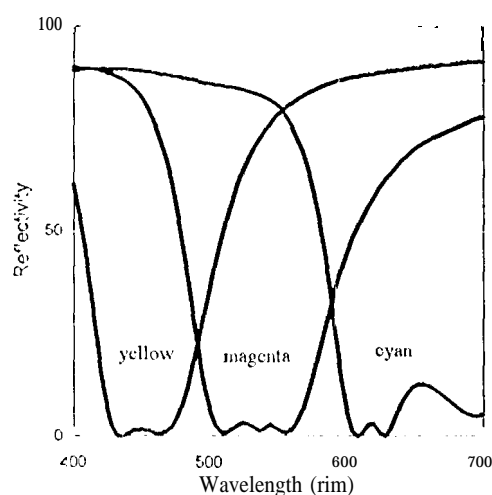


Fig. 2. Absorption spectrum of multiple layer metal film.

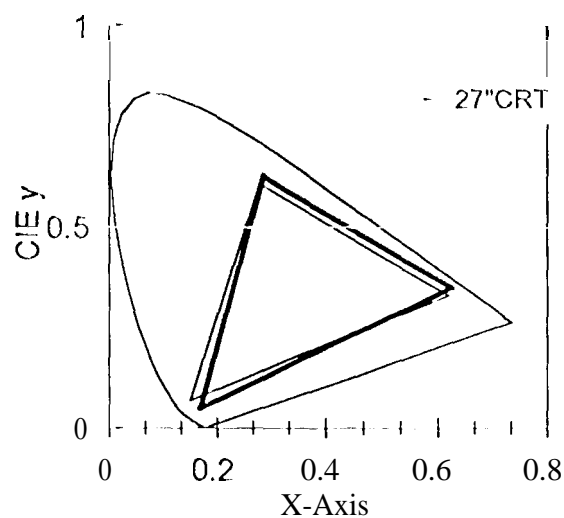


Fig. 3 Color gamut of SP color tunable filter.

If the $S1'$ resonance is wide enough to cover all of the visible spectrum, a white light modulator can be built. Fig. 4 show the theoretical calculation of using rhodium-aluminum two layer metal film system. Without voltage, the $S1'$ resonance is so wide that it covers all of the visible spectrum, and no light is reflected. When a voltage is applied, the reflected light begins to increase, and almost colorless. The highest reflectivity is over 80%, and we have grey scales in between. The contrast ratio can be better than 2.00:1.

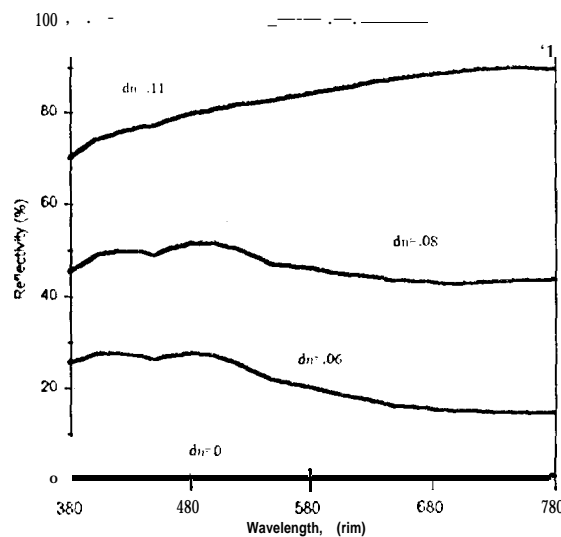


Fig. 4 Theoretical calculation of reflectivity tuning ability using Al-Rh film. When the index of liquid crystal changes from 0 to 0.11, the reflectivity changes from 0 to over 80%.

4. S1' sequential color projection display

A sequential color S1' projection display should be the first approach. Such a device can generate bright image with simple structure. It is formed by adding a many-pixel unit to the tunable color filter discussed above. This many pixel unit used Rh-Al film, and it has S1' resonance wide enough to cover all of the visible spectrum, Fig. 5 shows the structure of such a device. The light from the lamp is collected by the reflector and then passes the front relay and the integrator to become uniformly distributed collimated beam. After passing the polarizer, the p-component of the light beam is incident on the S1' device, and being reflected four times inside the glass prism. The first three reflections function as a tunable color filter to provide the sequential primary colors (red, green and blue), and upon the last reflection, the many pixel unit creates the image. This image is then projected on a screen by the projection lens. To address the system, a semiconductor chip can be used as the substrate for this many pixel unit. Such a projector can generate very bright image since these units are working at the reflection mode, the substrate silicon is good heat conductor, and another heat absorber can be attached to the silicon to extract the heat.

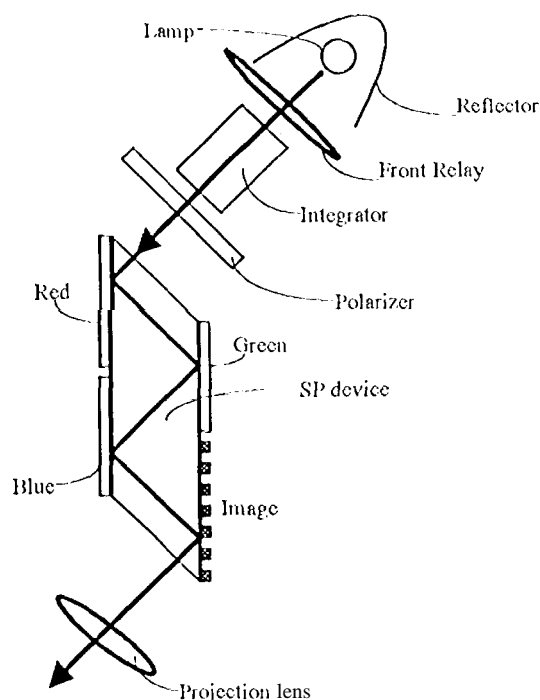


Fig. 5 Single panel surface plasmon projector. The first three reflections generate the sequential color, the last reflection generates the image.

By using the new Philips 100-w lamp with polarization conversion, its luminous efficiency can reach 3 lumens/Watt, which is better than many of the three panel 1.01 light valve projectors. And the simple structure and compact size are the other important merits. Notice this device is a sequential color projector, which 2/3 of light is lost. The efficiency and brightness will be tripled if all of the colors are used, as we will discuss in the future.

References:

1. Yu. Wang, Applied Physics Letters, 67, 2759 (1995).
2. H.J. Simon, et.al, Am. J. Phys. 43, 630 (1975)
3. Y. Wang and H.J. Simon, optical and Quantum Electronics, 25, S925 (1993).
4. J. S. Schildkraut, Appl. Opt. 27, p4587 (1988).
5. G.T. Sincebox and J.G. Gorton, Appl. Opt. 20, p1491 (1981).
6. E.M. Yeatman and M.E. Caldwell, Appl. Phys. Lett. 55, p613 (1989).
7. E.M. Yeatman and M.E. Caldwell, Appl. Opt. 31, p3880 (1992).
8. Yu Wang, to be published.